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VISUALIZATION OF THE MULTIPLE SUPERSONIC JET OSCILLATIONS BY SWEPT FOCUSED STROBED SCHLIEREN TECHNIQUE

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ABSTRACT

The natural flapping mode oscillations of a multiple rectangular supersonic jet is visualized by the newly developed strobed focusing schlieren technique. Four parallel underexpanded, converging rectangular jets, exhausting into ambient air at a fully expanded Mach number of 1.61 are visualized in this study. This technique clearly shows the oscillations at the natural screech frequency and offers tremendous flexibility in the study of these flow fields.

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1. INTRODUCTION

The three techniques of flow visualization for supersonic flows namely schlieren, shadowgraph, and interferometer provide average information along the optical path. For some research applications, the spatial averaged images lack the detailed information needed at a specific point in the flow field. An improved version of focusing schlieren technique which was first applied about 40 years ago is capable of producing images which are focused in planes perpendicular to optical axis.

If the flow is oscillating at a specific fundamental frequency, and if it is necessary to freeze the motion for detail studies, a special strobe light with triggering mechanism will be necessary.

The purpose of this paper is to explain the design of a strobed focused schlieren technique and its application in visualization of the natural flapping oscillations of multiple underexpanded supersonic rectangular jets[1].

2. EXPERIMENTAL SET-UP & Instrumentation

2.1 Supersonic Air Flow Facility

An existing cold jet facility at NASA Lewis Research Center was modified with the addition of 4 identical convergent rectangular nozzles. A Schematic drawing and a photograph of the flow facility are shown in Figs. 1 & 2 respectively. The 76 cm plenum tank and the optical beam supporting the swept strobed focusing schlieren system are clearly seen in Fig. 2.
The exit dimensions of each rectangular nozzle was 6.9 by 34.5 mm having an aspect ratio of 5. These nozzles produced 4 parallel supersonic jets at equal spacing and at fully expanded Mach number of about 1.61. The spacing between the nozzles could be adjusted to achieve screech synchronization at the operating conditions as shown in figure 3. For exit Mach number of 1.61, the spacing between the nozzle centerlines turned out to be 6.35 cm. The

individual nozzle total pressures could be maintained to within ±0.1 psi by remote control valves.

2.2 SWEPT FOCUSING STROBED SCHLIEREN SYSTEM

The focused schlieren system seen in Figures 2 & 4, was originally designed resembling that of Weinstein[2]. A conditionally triggered strobe light control system modeled after that described by references 3,4, and 5 was built in-house and used as the light source. A sketch of the video system is shown in figure 5 taken from reference 5. A microphone placed at the exit of each nozzle acquired the screech synchronization signal which was then band-pass filtered to eliminate the unwanted spectral components. A comparator adjusted to detect zero crossings produced the pulse train designated as "screech trigger" in figure 5. The system was designed to provide one pulse per video field. A sync pulse derived from the video camera flagged the initiation of a video field 60 times per second. The strobe was triggered on the leading edge of the first screech pulse after the video sync pulse. A variable delay with a continuously variable clock frequency, allowed the light source to be flashed at an arbitrary phase of the screech cycle. A sequence of video images acquired by slowly increasing the phase, effectively produced a slow-motion record of the jet unsteadiness that was phased to the screech tone[5]. With a fixed phase delay, the flapping motion of the jet could be stopped for viewing. The phase delay could also be continuously delayed through one cycle of the screech and the video monitor displayed the flapping motion of the jet instability.

A photograph indicating the interaction of the shock structure of a rectangular bevel supersonic jet with a Pitot tube taken by the standard focused schlieren is shown in figure 6. The natural flapping oscillations of a multiple supersonic jet at screech frequency is shown in figure 7.

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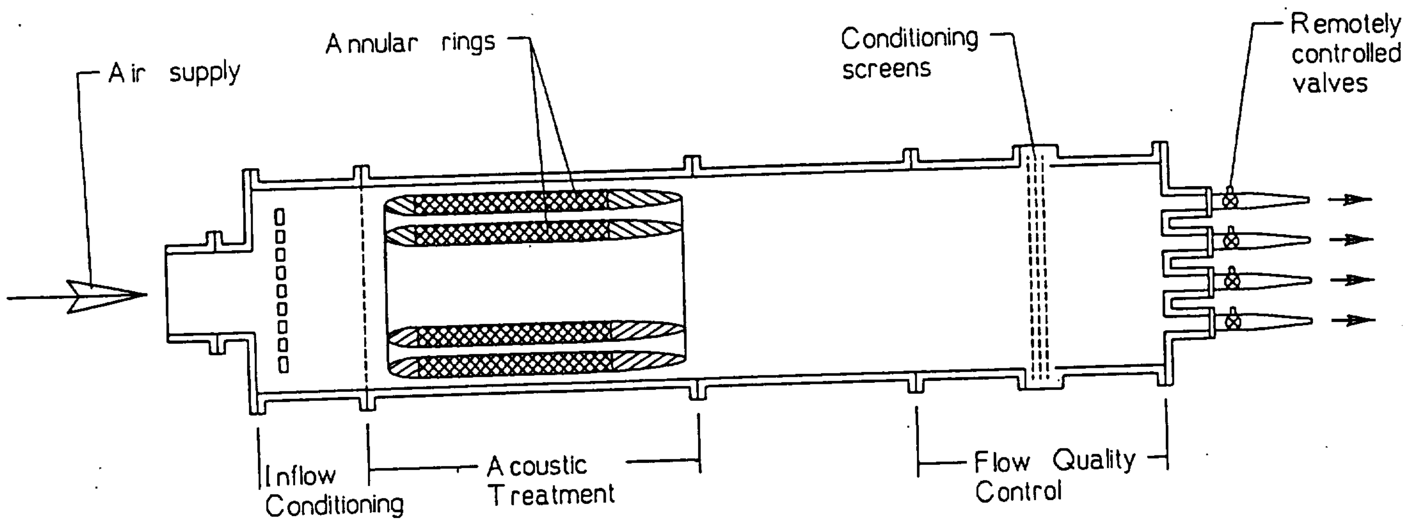


Fig. 1. Schematic of the supersonic jet flow facility.

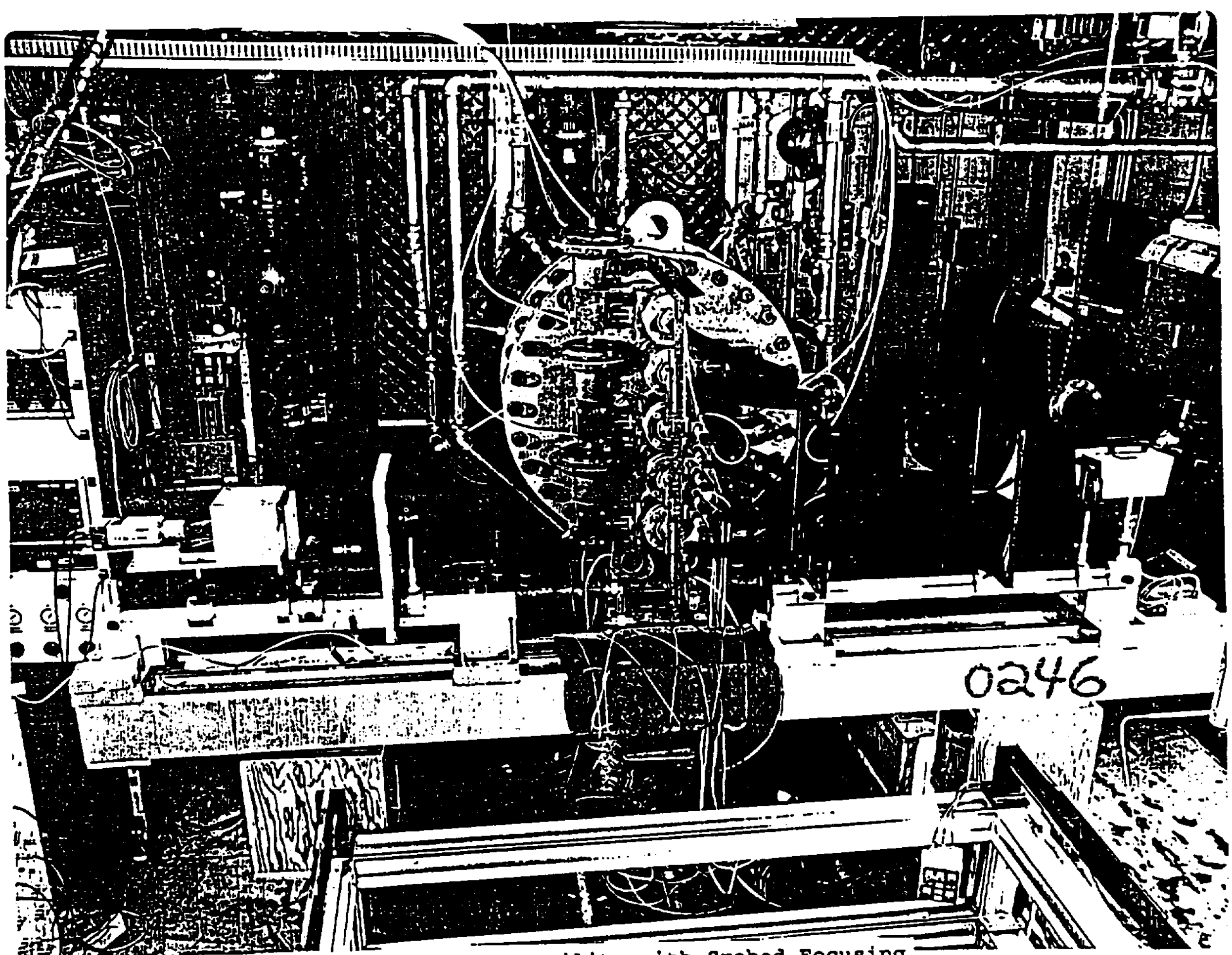


Figure 2. Multiple Jet Facility with Srobed Focusing Schlieren set-up.

Figure 3. Close-up of four rectangular nozzles, Microphones

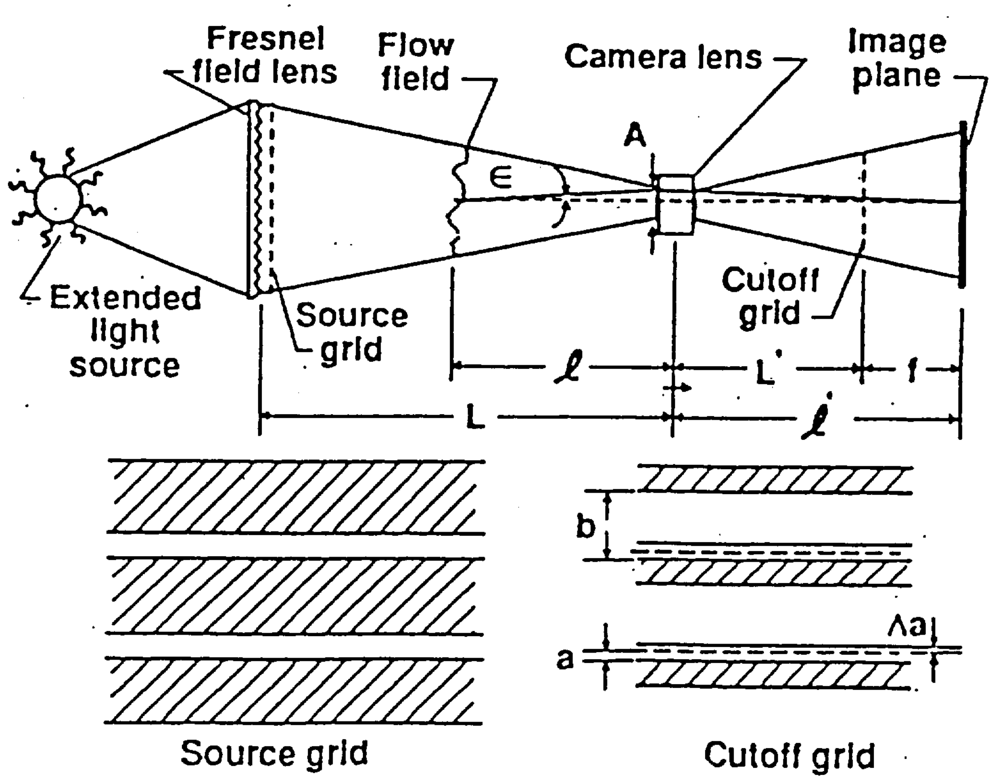


Figure 4. High Brightness Large Field Focusing Schlieren System[2]

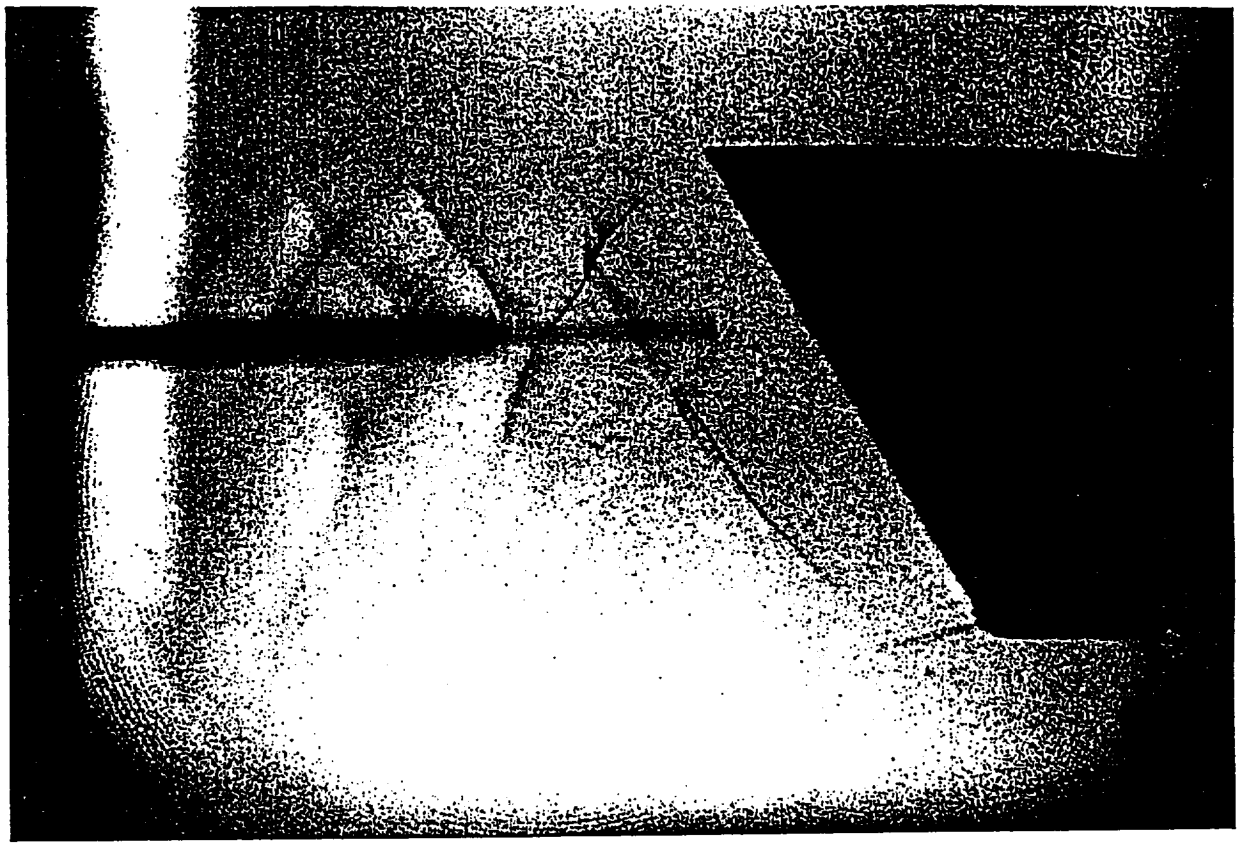


Figure 6. Bevel-Rectangular Jet Shock Structure.

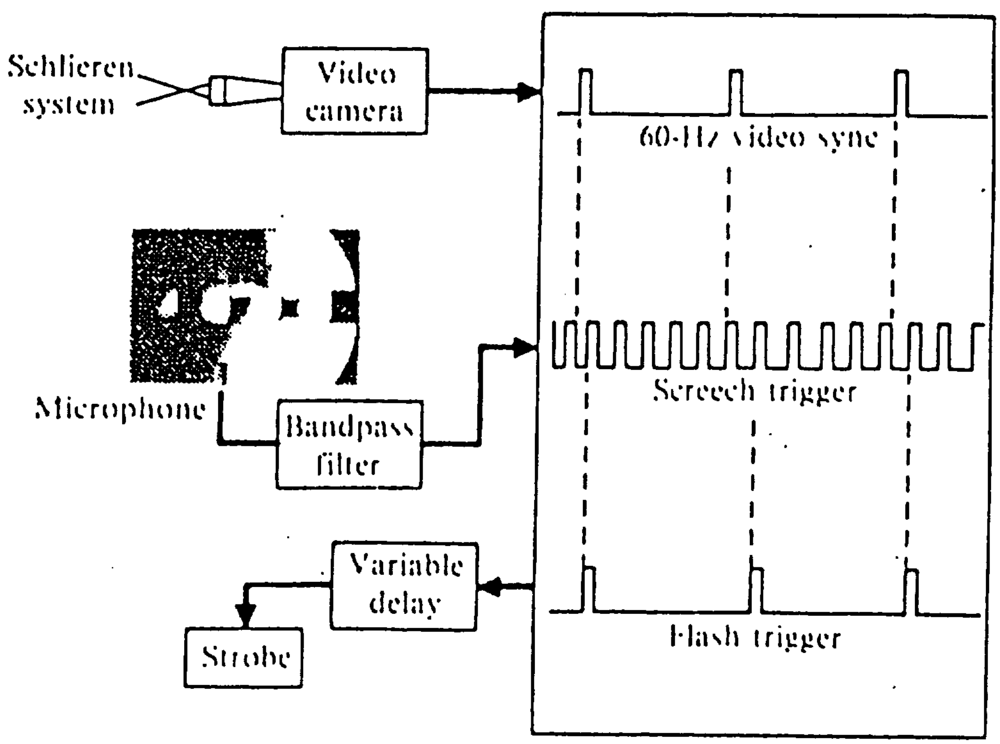
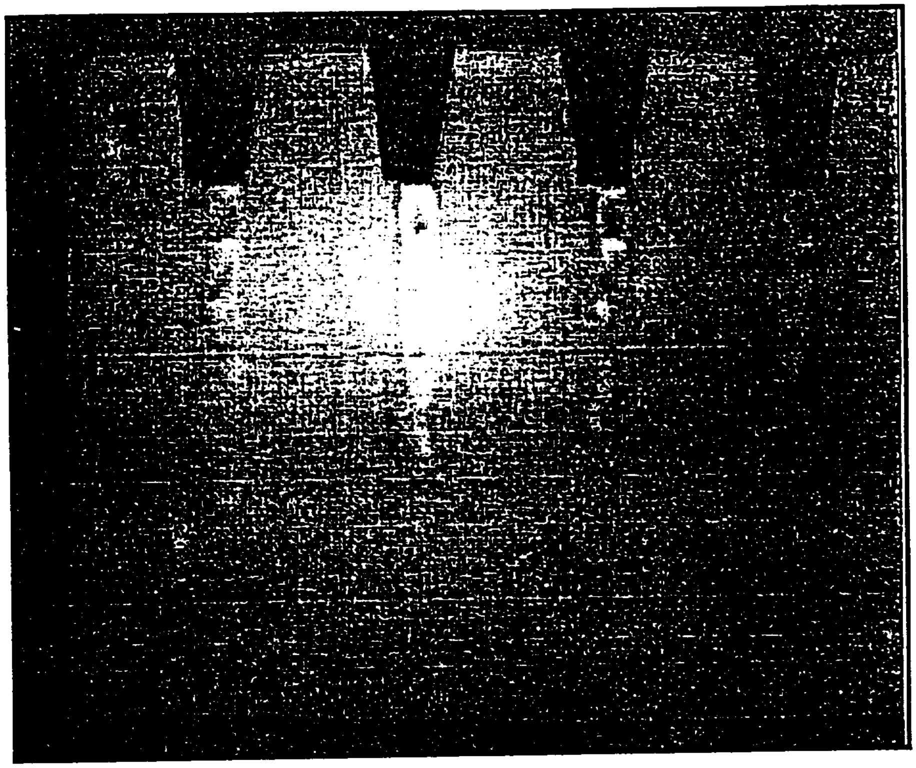
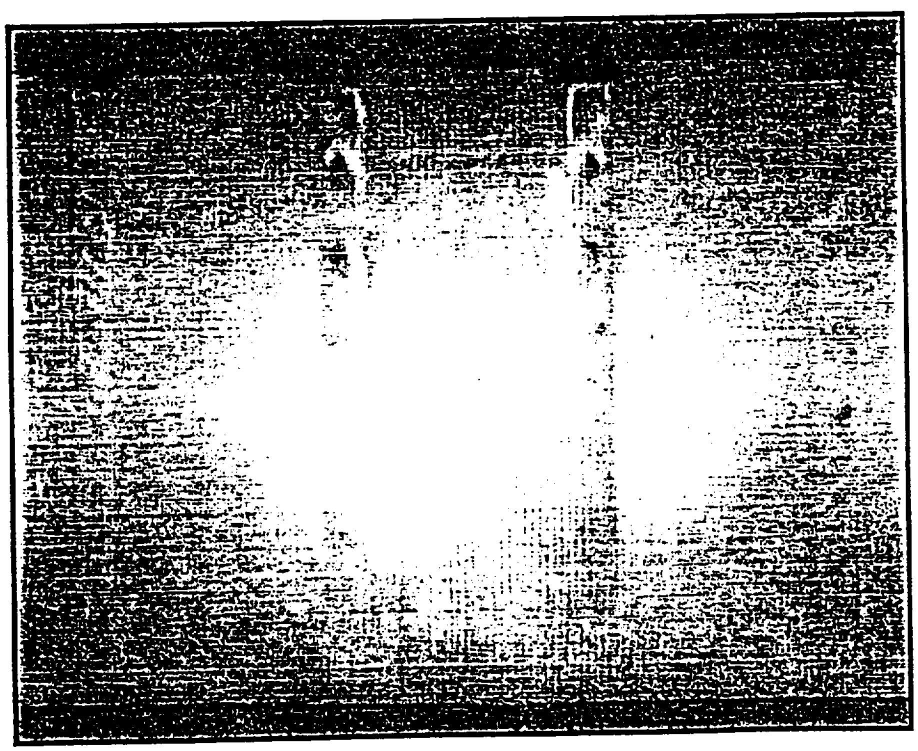


Figure 5. Phased-Conditioned Schlieren Video System[5]



a) Synchronized Screech



b) Screech Suppressed

Figure 7. Four Rectangular Supersonic Jets Flapping In Phase.